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Preferences for Energy Retrofit Investments Among Low-Income Renters

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Abstract

Energy poverty research has received increased attention in the energy economics literature in recent years. We analyze the preferences of low-income renters in the city of Graz, Austria, for different energy retrofitting options. Using data collected from a Discrete Choice Experiment, we find that households are willing to forego significant future energy cost savings in order to avoid investment costs in the present. This can be caused by several factors, including liquidity constraints, a short investment horizon, and myopia among the participants. Furthermore, participants show a significant Willingness to Pay for the reduction of CO_2 emissions. We also present simulations for different forms of subsidies for retrofitting and their effects on market shares and emissions. The results have important policy implications regarding the optimal subsidy policies, in particular for low-income households. Specifically, policy makers should focus on reducing the investment burden for liquidity-constrained renters and inducing a longer investment horizon.

JEL Classification: C35; D12; Q48; Q51

Keywords: Energy Poverty; Discrete Choice Modeling; Residential Energy Consumption; Landlord-Tenant Problem

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1 Introduction

Improving energy efficiency through home energy retrofits is considered one of the most effective and cost-efficient ways to reduce energy consumption in the residential sector and achieve the climate policy goals set by many actors worldwide. Furthermore, it is a tool to mitigate energy poverty.

Low-income households can be a fruitful focus area for policy makers because of two reasons: Firstly, they usually live in less energy-efficient buildings compared to higher income households (Carroll et al., 2016). Therefore, these buildings offer high potentials for energy savings. Secondly, subsidizing low-income households in particular may reduce inequality and energy poverty, both of which are stated policy goals in many countries (Seebauer et al., 2019), and may also enhance social welfare.

Because home energy retrofits present social benefits which homeowners and landlords may not fully take into account, we can expect them to be conducted less often than would be socially optimal. However, the adoption of energy retrofits in residential homes has long been at a suboptimal level not only socially, but also privately (Jaffe and Stavins, 1994). Several possible explanations for this energy efficiency gap exist, including inefficient pricing of energy consumption and information asymmetries between energy providers and consumers (Best et al., 2021; Gerarden et al., 2017). Another reason is limited access to capital, which can also occur in combination with debt aversion (Schleich et al., 2021).

In rented accommodations, the possibility of split incentives makes this issue even more complex; usually, the landlord has to bear the cost of energy efficiency improvements, while the tenant reaps the benefits through lower energy costs. This may lead to low efficiency investments by landlords if the investment costs cannot be fully recouped through higher rents. Tenants, on the other hand, may also be hesitant to invest money in a property that they do not own, and consequently tend to avoid efficiency investments (Ástmarsson et al., 2013; Trotta, 2018). This landlord-tenant problem has been investigated extensively in the literature (see, e.g., Gillingham et al. 2012; Levinson and Niemann 2004; Melvin 2018).

Regarding energy retrofit decisions, the preferences of renters are not well researched so far. Given that renters profit from efficiency investments through lower energy bills, they may be willing to share some of the financial burden of the initial investment. Due to the high share of renters in many countries, including Austria, unlocking the energy retrofitting potential of rented dwellings is therefore a worthwhile endeavor for policy makers. This, however, necessitates to learn more about renters' preferences regarding energy retrofits.

The empirical literature on such preferences remains scarce. Achtnicht (2011) estimates the Willingness to Pay for energy efficiency improvements of homeowners using a Discrete Choice Experiment. The author finds that the participants include both cost savings and CO_2 savings in their choices in the experiment. Kwak et al. (2010) use a Discrete Choice Experiment (DCE) to estimate households' preferences for specific energy-saving measures such as double glazed windows and thicker wall insulations. They find moderate, but statistically significant WTP values for these measures. Using survey data from Ireland, Collins and Curtis (2018) estimate the WTP of renters for energy efficiency improvements in the form of a rent premium. The authors find significant WTP values for energy efficiency increases, with significant variation depending on the specific measure in question and on demographic characteristics of the renters.

In the present study, we focus on the following six research questions:

RQ1: Under which financial circumstances are tenants willing to invest in energy retrofits in their rented accommodations?

RQ2: What is the implied rate of return needed for these investments?

RQ3: Is there a preference for fairness, meaning that renters are willing to pay more for a retrofit if landlords/-ladies are also investing more?

RQ4: Which role, if any, do CO_2 savings play in the energy retrofit investment decision?

RQ5: How do demographic characteristics influence these preferences?

RQ6: What are the implications of these findings for energy retrofitting subsidies in the residential sector?

Using a DCE, we shed light on the preferences of renters for different hypothetical retrofitting options. DCEs are a relatively straightforward and flexible way to assess consumer preferences and valuations on a range of hypothetical products and outcomes. There is a wide field of potential applications for DCEs, such as marketing, public economics, and environmental economics.

The contribution of this article to the existing literature is at least twofold: Firstly, it adds to the scarce literature on experimentally investigating the preferences of renters to invest in their rented accommodations. Secondly, it derives policy implications on possible subsidies for energy retrofits based on the experimental results. These insights can help policy makers aiming at promoting retrofitting among renters, in particular those with lower incomes.

The remainder of this article has the following structure. Section 2 describes the dataset generated by the experiment and presents descriptive statistics. Section 3 discusses the methodology used in the analysis. The main results are presented in Section 4. Section 5 reports on illustrative simulation results for different subsidy options that could be enacted to promote the willingness to adopt energy retrofit measures. Section 6 concludes.

2 Data

2.1 Experimental Design

To generate the data used in this study and answer the questions outlined in the previous section, a DCE was designed and conducted among a sample of low-income renters living in Austria. When designing a DCE, the choice of attributes and attribute levels is of fundamental importance for the results and interpretation of the experiment. Ideally, all attributes that are relevant to the simulated decision-making process would be included. However, this would often result in using a prohibitively large number of attributes. Apart from computational challenges in choice set generation, including too many attributes can also lead to a high cognitive burden on the participants. This may result in participants using simplifying heuristics, ignoring certain attributes, or abandoning their participation in the experiment altogether (DeShazo and Fermo, 2002; Mangham et al., 2008; Johnson et al., 2013).

As a compromise between limiting the cognitive load and still allowing for an accurate description of the choice situations, four attributes were chosen, with four levels each. Table 1 shows the different attributes and their levels used in the experiment.

The attributes are based on the research questions listed in the introduction as well as previous literature (see e.g. Achtnicht, 2011). The attributes ‘cost savings per month’ and ‘investment cost renter’ relate to RQ 1 and RQ 2 and create the monetary foundation of the investment decision. Depending on the choice cards, higher energy cost savings may come at a higher initial investment cost, which reflects the situation that those who are interested in a home retrofit often face in reality. If the participants were entirely motivated by financial incentives, we would expect them to focus only on these two attributes and disregard the other two.

Table 1: Attribute levels

Attribute	Possible values			
Energy cost savings per month	5%	10%	15%	20%
Investment cost renter, in Euros	500	1000	1500	2000
Investment cost owner, in Euros	1000	2000	3000	4000
CO_2 emission savings	25%	50%	75%	95%

Note: The energy cost savings were calculated in % based on the reported energy costs of the individual participants. For the sake of clarity and ease of interpretation, these savings were presented to the participants as Euro values in the choice cards.

The 'investment cost owner' attribute helps to assess the renters' preferences on cost sharing of energy efficiency investments (RQ 3). Perceived fairness of cost distribution can be a significant factor in the acceptance of climate policy measures (Drews and van den Bergh, 2016). Different types of fairness principles exist. In the literature, researchers differentiate between three types of distributive justice, namely: (1) equal-pay, where each party pays the same amount; (2) polluter-pays, where individuals pay based on their specific consumption or pollution levels; and (3) ability-to-pay, where each participant pays based on his/her economic situation (Groh and Ziegler, 2018; Seebauer and Eisfeld, 2010). While the specific preferences regarding these different distributional mechanisms are beyond the scope of this experiment, we can still assess whether the participants' decision is influenced by the amount that is paid by their landlord/-lady.[1]

Finally, we included the attribute on CO_2 emission savings to be able to answer RQ 4. Several studies find a significant and positive stated WTP for the reduction of CO_2 emissions through retrofits (Alberini et al., 2018). Including this attribute therefore serves to corroborate these findings from other studies and evaluate whether these results can be confirmed for the case of low-income renters. Furthermore, it allows us to quantify the WTP for CO_2 reduction through energy retrofitting measures.

In order to avoid effects based on preconceived notions or prejudices of the participants towards specific types of retrofits, we abstract from the specific nature of the retrofit in the choice cards. The number of alternatives in each choice situation, and the number of choice situations that each participant faces, also have to be chosen by the researcher. As a compromise between high retention and achieving a larger sample size, each respondent was asked to complete seven choice cards, with two alternatives A and B in each choice card. The choice sets were generated using a balanced overlap design via the Sawtooth Lighthouse Studio Software, which was also used to host the experiment.

Another choice to be made by the researcher is whether to include the 'None of the above' option, which participants can check whenever none of the choices in a particular choice card appeal to them. This decision has implications for the analysis and interpretation of the results and should be based on the choice situation that is simulated. In the case of retrofits, it appears reasonable to include a 'None' option, since in reality people usually have the option to not conduct or agree to a retrofit. We use the 'Dual-Response None' approach, where, in the first step, participants are asked which of the two options they find more attractive. In the second step, they are asked whether or not they would actually conduct this retrofit if given the chance. Answering 'No' to the second question is then interpreted as choosing the 'None' option in a traditional {A, B, None} framework. This has the advantage that the participants' preference is still known even if they choose the 'None' option in the second step. In the case of a large share of 'None' answers, the additional preference data from the first step can then still be used (Brazell

[1] For a more thorough discussion of this topic, see Seebauer and Eisfeld (2010).

et al., 2006).

The participants were recruited from an online sample, based on participants of a mail-in survey conducted among beneficiaries of a social assistance program in the city of Graz, Austria (Seebauer and Eisfeld, 2010). All participants in the survey reported in Seebauer and Eisfeld (2010) who agreed to participate in the experiment were invited via E-mail; participation was incentivized via the chance to win an online gift card. Out of those 271 potential participants, 76 people took part in the experiment. The experiment was conducted between November 2020 and January 2021. Two reminders were sent in December 2020 and January 2021, respectively. At the start of the survey, participants received an explanation that their choices were hypothetical and that no actual renovation would be made based on their answers. Demographic data on the respondents were obtained previously in the survey described in Seebauer and Eisfeld (2010). Demographic and experimental data were then matched based on the E-mail addresses of the participants. Due to mismatches in the E-mail addresses between the two surveys, not all participants could be matched to the demographic survey. In this matched data set, the sample size was reduced to 65 participants, representing a total of 422 choice situations. All participants who answered at least one choice card were included in the sample. We analyze both the full (unmatched) and the reduced (matched) data sets.

2.2 Descriptive Statistics

This section presents the demographic attributes of the participants in the experiment. Table 2 shows the descriptive statistics of the sample. Only those households that could be matched to the first survey, as described in the previous section, are included in the table.

Table 2: Descriptive statistics

Statistic	Unit	Mean	St. Dev.	Min	Max
Monthly net household income	Euros	1133.333	381.530	400	2450
Social assistance	1 = Yes	0.841	0.368	0	1
Able to save some money monthly	1 = Yes	0.328	0.473	0	1
Monthly savings amount	Euros	43.492	87.697	0	400
Monthly heating cost	Euros	67.472	58.268	2	400
Monthly electricity cost	Euros	53.322	23.009	20	110
Monthly rent	Euros	485.508	203.643	138	1196
Difficulty paying for heating	1 = Yes	0.203	0.406	0	1
Difficulty paying for rent	1 = Yes	0.095	0.296	0	1
1- or 2-family home	1 = Yes	0.062	0.242	0	1
Apt. in 3-10 unit bldg.	1 = Yes	0.323	0.471	0	1
Apt. in 10+ unit bldg.	1 = Yes	0.615	0.490	0	1
Built before 1919	1 = Yes	0.092	0.292	0	1
Built 1919 - 1944	1 = Yes	0.108	0.312	0	1
Built 1945 - 1980	1 = Yes	0.508	0.504	0	1
Built 1981 - 2000	1 = Yes	0.169	0.378	0	1
Built 2001 or later	1 = Yes	0.123	0.331	0	1
Living space	Square meters	53.946	16.563	28	96
Unlimited rental contract	1 = Yes	0.600	0.494	0	1
Planning to live here permanently	1 = Yes	0.679	0.471	0	1
Household size	# of people	1.873	1.251	1	5
Gender of respondent	1 = Female	0.438	0.500	0	1

As mentioned previously, the sample mainly consists of low-income households. This is shown in the household income variable, which has a mean of 1133 Euros per month and a median of 900 Euros per month.[2] In comparison, the mean net household income across Austria was 4496.82 Euros per month in 2019.[3]

Only 32.8% of the households surveyed do report that they are able to save some amount of money at the end of a typical month. The mean of these monthly savings is 43.49 Euros, which is significantly lower than for a typical Austrian household. In 2019, for instance, the mean monthly savings amount across all private households in Austria was 386.17 Euros.[4] In our sample, more than 44% of households report that they have 'problems' or 'severe problems' handling their finances given their income situation. The average living space is 53.95 square meters, with an average household size of 1.87 inhabitants. 40.0% of the households have a fixed-term rental contract, with an average duration of 3.74 years remaining. 93.8% of respondents live in buildings with 3 or more units, and 70.8% live in homes that were built before 1981.

3 Methodology

We utilize a discrete choice framework, based on the random utility model (McFadden, 1974; Train, 2009). We make the assumption of characteristic space, which states that the utility of a choice or product is purely a function of its attributes and attribute levels. The utility of individual n for alternative i in choice situation t can be described as

$$U_{nit} = V_{nit} + \epsilon_{nit}, \tag{1}$$

where V_{nit} denotes the deterministic component and ϵ_{nit} is the unobserved stochastic component, which is assumed to be independently and identically distributed (i.i.d.) following a Gumbel distribution. In each choice situation t, households choose the option which has the highest utility, which means that

$$U_{nit} > U_{njt} (\forall i \neq j). \tag{2}$$

Following McFadden (1974), the probability that individual n chooses alternative i can be written as

$$\begin{aligned} P_{ni} &= Prob(V_{ni} + \epsilon_{ni} > V_{nj} + \epsilon_{nj} (\forall i \neq j)) \\ &= Prob(\epsilon_{nj} < \epsilon_{ni} + V_{ni} - V_{nj} (\forall i \neq j)). \end{aligned}$$

This type of distribution leads to an S-shaped relationship between the representative utility V_{nit} and the choice probability P_{ni} (Train, 2009).

The deterministic utility component V_{nit} can then be written as

$$V_{nit} = \beta^a_{nit} msav_{nit} + \beta^b_{nit} rcost_{nit} + \beta^c_{nit} ocost_{nit} + \beta^d_{nit} esav_{nit}, \tag{3}$$

with $msav_{nit}$, $rcost_{nit}$, $ocost_{nit}$, and $esav_{nit}$ as indicators for the monetary savings, renter investment cost, owner investment cost, and emission savings attributes, respectively. The parameters of interest

[2] Monthly net household income was assessed categorically, with a total of six categories, ranging from 'up to 800 Euros' to 'more than 3000 Euros'. In Table 2 and in our further analysis, the categories are converted to numerical values by taking the midpoint of each category.

[3] Own calculations based on Statistik Austria (2020a,b).

[4] Own calculations based on Statistik Austria (2020a,b).

estimated by the model are β^a, β^b, β^c, and β^d.

4 Results

4.1 Main Results

Table 3 shows the coefficients of our preferred model specification. These estimates are only based on the results obtained from the Discrete Choice Experiment, without taking demographic and other characteristics into account. Therefore, these estimations only contain the alternative-specific variables monetary savings, renter cost, owner cost, and CO_2 savings. In Section 4.2, we also discuss the results from a specification that includes the demographic characteristics of the participants. Model 1 includes the 'None' option, while Model 2 only considers the participants' choice between options A and B.

Table 3: Two main models, without demographics

	Dependent variable: Choice	
	(1)	(2)
	Including NONE option	Excluding NONE option
Monetary savings	1.127***	1.001*
	(0.406)	(0.564)
Renter cost	−0.642***	−0.718***
	(0.108)	(0.111)
Owner cost	−0.052	−0.125**
	(0.051)	(0.054)
CO_2 savings	0.006***	0.005**
	(0.002)	(0.002)
Observations	495	495
Log Likelihood	−517.198	−315.115

Notes: ***, **, and * indicate significance at the 0.01, 0.05, and 0.10 levels, respectively. Clustered robust standard errors in parentheses.

With the exception of owner cost in Model 1, all of the estimates are statistically significant at least at the 10% level, with most of them also being significant at the 5% level. The coefficient estimates have the expected signs. Higher savings both in terms of energy cost and CO_2 increase the likelihood of choosing a given option, while the two investment cost variables have negative signs. As anticipated, the effect size of renter cost is larger than that of owner cost. While households have a preference for a lower investment cost for their landlord, their own investment cost is a much stronger factor in the decision for or against a certain choice card. This is to be expected: the most important determinants renters take into account when making a retrofitting decision are their own monetary costs and benefits.

For the owner cost variable, different interpretations are possible. From a purely economic point of view, the cost for the owner should not matter for the participants' decision. In this case, the coefficient estimates would not be statistically significant, which is the case for Model 1, but not for Model 2. Other factors might also be involved here: renters may have a preference for lower owner cost as a form of altruism, potentially due to having a personal relationship with their landlord. The opposite effect is also feasible: Renters may be willing to invest more if their landlord also invests due to a preference for sharing the investment cost in a way that they perceive as fair. Either way, the small negative coefficient we find shows that renters seem to have a slight preference for a lower investment cost of owners. As expected, the owner cost is a much less significant factor for the participants in their decision making, compared to their own investment cost.

Finally, the CO_2 savings coefficient is significant and negative, which indicates that the participants take the potential CO_2 savings into account when choosing a retrofitting option. The coefficient for the CO_2 savings variable is the largest out of all coefficients in both models. However, these values are not directly comparable due to the different units. Still, the results suggest that the participants take the potential CO_2 savings into account when evaluating different retrofitting options.

Unlike in a regular OLS regression, the coefficient estimates depicted in Table 3 cannot be directly interpreted as percentages due to the non-linear relationship between choice probability and representative utility. However, we can derive marginal effects from the coefficients, as shown in Table 4. These marginal effects denote the change in selection probability if the accompanying attribute is increased by one unit, i.e. one Euro for the investment cost and monetary savings variables and one percentage point for the CO_2 savings. For example, a retrofit that is 100 Euros less expensive for the renter would, *ceteris paribus*, have a 1.36% (Model 1) to 1.79% (Model 2) higher chance of being selected. While the relationship between coefficient estimates and marginal effects is non-linear due to the sigmoid shape of the cumulative distribution function, larger coefficients are still correlated with larger marginal effects, as Table 4 shows.

Table 4: Marginal effects, in %

Variable	Model 1	Model 2
Monetary savings, in 1000 Euros	0.2385***	0.2498*
Renter cost, in 1000 Euros	−0.1360***	−0.1793***
Owner cost, in 1000 Euros	−0.0110	−0.0313**
CO_2 savings, in %	0.0014***	0.0012**

Notes: ***, **, and * indicate significance at the 0.01, 0.05, and 0.10 levels, respectively.

Based on the coefficients depicted in Table 3, we can calculate the WTP for the attributes used in the experiment. This is achieved by dividing one coefficient estimate by another. This ratio signifies the amount of one attribute (e.g. investment cost in Euros) that consumers are willing to give up in order to increase or decrease another attribute by one unit (e.g. CO_2 savings in %). In principle, this relationship can be calculated between any two attributes. Usually, however, a variable that is expressed in monetary terms is used as the denominator, such as renter cost in our case. This allows for easier interpretation of the obtained values. Table 5 shows the mean WTP for the different attributes in Euros, obtained by dividing the coefficient estimates for the different variables by the renter cost coefficient.

Table 5: Willingness to Pay, in Euros

Variable	Model 1	Model 2
Yearly energy cost savings, in Euros	1.75	1.39
Renter cost, in Euros	1.00	1.00
Owner cost, in Euros	−0.08	−0.17
CO_2 savings, in %	9.96	6.72

As Table 5 shows, households are willing to pay between 1.39 and 1.75 Euros in additional investment cost today to save 1 Euro in energy costs every year. Additionally, they are willing to invest 6.72 to 9.96

Euros to save one additional percentage point of CO_2 emissions in their home. The WTP to lower the investment cost for the homeowner by 1 Euro ranges from 0.08 to 0.17 Euros. The WTP for the variable 'Renter cost' is, by definition, 1 Euro.

Based on these WTP values, specifically on the WTP for the yearly savings variable, we can calculate the implied Internal Rate of Return (IRR) of the retrofitting investment. The IRR is defined as the discount rate for which someone is just indifferent between investing and not investing. It can be calculated by using the formula for the Net Present Value,

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1 + IRR)^t} - C_0, \tag{4}$$

with C_t as the net cash flow in time period t. Setting the NPV to 0 and solving numerically yields the IRR.

Table 6: Internal Rate of Return, in %

Timeframe, in years	1	2	3	4	5	10	20
Model 1	-42.99	9.22	32.51	43.61	49.34	56.36	57.01
Model 2	-28.25	27.86	50.84	61.10	66.07	71.42	71.75

The empirical literature on the IRR of retrofitting and investments in energy-efficient technologies reports a broad range of rates, that is dependent on the applied methods and the specific type of investment that is investigated. However, the majority of studies find rates that are significantly higher than the interest rates observed in financial markets (Schleich et al., 2016).

The IRR depends on the assumed time horizon of the investment, which may vary between individuals. Table 6 shows the implicit yearly IRR for different investment horizons. The values show that for an investment period of 3 or more years, the rate of return that participants implicitly expect grows excessively large.

There are several possible explanations for this observation. Firstly, households may have a very short time horizon when considering this investment; the WTP values imply an expected payback period of 21 months, which is substantially shorter than the expected lifetime of most possible retrofitting options. Still, this short time horizon may be appropriate if renters expect to move out within the foreseeable future. Secondly, households might also strongly discount future cost savings, which may be a sign of present bias. Thirdly, low-income households often have low access to liquidity and would not be able to invest any substantial amount of money in the first place, which limits the amount of money they are willing or able to invest today, even if this results in foregoing larger future cost savings.

4.2 Demographic Interactions

Combining the data obtained in the DCE with the demographic data from the previous survey described in Seebauer and Eisfeld (2010) yields additional insights into renters' preferences. To this end, we first match the two datasets. Since not all observations could be matched, this reduces the sample size from 495 choice situations of 76 respondents to 422 choice situations of 65 respondents. In an unlabeled experiment, individual characteristics can only be meaningfully included if they are interacted with product attributes. Adding demographic data allows us to reveal a more differentiated picture of the experimental results.

4.2.1 Income

Related studies have found that the willingness to make an investment is dependent on household income, with higher income households being more willing and able to invest into retrofits (Newell and Siikamäki, 2015). To corroborate this, we separate our sample by yearly household income in the following estimations. Specifically, we divide the sample into a higher and lower income group, at the median monthly household income of 1200 Euros.[5] Table 7 shows the estimation results when differentiating by income. Column 3 shows the full sample with interactions between income and the energy cost savings and renter cost variables, respectively.

Table 7: Estimations including income

	Dependent variable: Choice		
	(higher income)	(lower income)	(interactions)
Energy cost savings	0.335	4.817***	8.255***
	(0.647)	(1.389)	(2.247)
Renter cost	−0.771***	−0.885***	−0.753**
	(0.202)	(0.179)	(0.348)
Owner cost	−0.165*	−0.072	−0.119*
	(0.092)	(0.084)	(0.062)
CO_2 savings	0.006	0.007**	0.006**
	(0.004)	(0.004)	(0.003)
Monetary savings * income			−0.005***
			(0.002)
Renter cost * income			−0.0001
			(0.0003)
Observations	171	199	370
Log Likelihood	−164.135	−197.228	−362.554

Notes: ***, **, and * indicate significance at the 0.01, 0.05, and 0.10 levels, respectively.

Table 7 reveals that there is a significant difference in the importance of 'monetary savings' between higher and lower income households, but this does not appear to be the case for 'renter cost'.

4.2.2 Tenure

As discussed in Section 4.1, in particular in Table 6, the implied rate of return may depend heavily on the expected time horizon of the investment, which in turn is influenced by the expected future duration of occupancy by the tenant. We therefore include the contract situation in our estimations in this section.

Table 8 shows the estimation results differentiated by the contract situation of the renter. For households with a time-limited contract, none of the variables are significant, which appears to be a byproduct of the small sample size for this subgroup.

While the small sample size proves to be a limiting factor, the third column shows that households with an unlimited rental agreement have stronger preferences for both higher energy cost savings and lower investment costs.

[5]Note that household income is denoted categorically; we therefore use the midpoint between the corresponding category limits as the mean income for each participant.

Table 8: Estimations including rental contract

	Dependent variable: Choice		
	(unlimited)	(limited)	(interactions)
Monetary savings	2.545***	−0.581	0.035
	(0.850)	(0.908)	(0.857)
Renter cost	−0.955***	−0.163	−0.016
	(0.189)	(0.180)	(0.159)
Owner cost	−0.198**	0.117	−0.040
	(0.091)	(0.087)	(0.062)
CO_2 savings	0.004	0.003	0.003
	(0.004)	(0.004)	(0.003)
Monetary savings * unlimited contract			2.196**
			(1.111)
Renter cost * unlimited contract			−1.118***
			(0.202)
Observations	217	141	358
Log Likelihood	−194.443	−153.206	−351.297

Notes: ***, **, and * indicate significance at the 0.01, 0.05, and 0.10 levels, respectively.

5 Simulation

In order to further illustrate our findings and derive some policy implications, we report on a number of simulations conducted for different subsidy scenarios that could be enacted in order to promote energy retrofits. The simulation results can give us an indication of which type and amount of subsidy could be the most effective.

Specifically, we simulate the market share for two exemplary retrofitting options, in addition to the 'None' option. As Table 9 shows, the two options A and B are calibrated with the lowest and highest levels for all attributes, respectively. Option C represents the 'None' option.

Table 9: Levels for simulation

Attribute	Option A	Option B	Option C
Energy cost savings per month	5%	20%	0%
Investment cost renter, in Euros	500	2000	0
Investment cost owner, in Euros	1000	4000	0
CO_2 emission savings	25%	95%	0%

The simulation is based on the model without demographic interactions presented in Table 3 of Section 4.1. We simulate a variety of scenarios, namely:

1. no subsidy;
2. a 25% subsidy of the renter's investment cost;
3. a 50% subsidy of the renter's investment cost;
4. a 50% subsidy of the renter's investment cost only for option B.

Through the coefficient estimates, changing the attribute levels influences the choice probabilities for the different options. In the aggregate, these choice probabilities can then be directly interpreted as market shares (Train, 2009).

Table 10: Simulation results

	Option A	Option B	Option C
Scenario 1: No subsidy			
Choice probability	36.09%	15.36%	48.55%
Subsidy expenditures per household, in Euros	0.00	0.00	0.00
CO_2 emission savings	9.02%	14.59%	0.00%
Subsidy cost for 1% reduction, in Euros	0.00	0.00	-
Scenario 2: 25% subsidy			
Choice probability	35.95%	19.39%	44.66%
Subsidy expenditures per household, in Euros	44.94	96.93	0.00
CO_2 emission savings	8.99%	18.42%	0.00%
Subsidy cost for 1% reduction, in Euros	5.00	5.26	-
Scenario 3: 50% subsidy			
Choice probability	35.33%	24.13%	40.54%
Subsidy expenditures per household, in Euros	88.32	241.33	0.00
CO_2 emission savings	8.83%	22.93%	0.00%
Subsidy cost for 1% reduction, in Euros	10.00	10.52	-
Scenario 4: 50% subsidy for Option B			
Choice probability	31.75%	25.45%	42.79%
Subsidy expenditures per household, in Euros	0.00	254.54	0.00
CO_2 emission savings	7.94%	24.18%	0.00%
Subsidy cost for 1% reduction, in Euros	0.00	10.53	-

Table 10 shows the simulation results for the different scenarios. The 'CO_2 emission savings' values represent the savings that are achieved in each scenario compared to a situation where no retrofits take place at all. These values are calculated by multiplying the emission savings for the two options from Table 9 (5% and 25%) with the choice probability of the respective option in each scenario. The total emission savings in each scenario can then be obtained by adding the savings values for options A and B. The values for 'Subsidy expenditures per household' are calculated by multiplying the subsidy for each option with the share of households who choose that option in the respective scenario.

Generally, lowering the investment cost for an option increases its attractiveness relative to the other options, which leads to a higher market share for that option. We find that without any subsidy, nearly half (48.55%) of the households would choose neither option A nor B, with the second most popular option being the cheaper option A (36.09%).

Apparently, while some households switch from option C to option A, roughly the same proportion of households move from option A to option B, which leaves the market share of option A virtually unchanged between scenarios 1, 2, and 3.

In scenario 4, option B is chosen at a significantly higher rate compared to the baseline scenario (25.45% compared to 15.36%).

In terms of cost effectiveness, the 25% subsidy in scenario 2 offers the best ratio of subsidy expenditures to CO_2 emission savings. Here, the CO_2 emission savings are 3.79 percentage points higher than in the baseline scenario, at an expected average subsidy expenditure of 141.89 € per household.

In all scenarios, we find large free rider effects, since more than half of the households (51.45%) would also conduct one of the two energy retrofits without receiving any subsidy.

Scenario 2 is the most cost effective one at 5.18 € in subsidies for each 1% of CO_2 emissions saved, while scenario 4 offers the highest total CO_2 emission savings, with an additional 8.51% of CO_2 emissions saved compared to the baseline scenario without subsidy.

Table 11: Simulation results, aggregated by scenario

Scenario	1	2	3	4
Subsidy expenditures per household, in Euros	0.00	141.89	329.63	254.53
CO_2 emission savings	23.61%	27.41%	31.76%	32.12%
Subsidy cost for a 1% emission reduction, in Euros	0.00	5.18	10.38	7.92

6 Conclusions

In this study, we assess the preferences of low-income renters regarding their willingness to invest in energy efficiency in their dwellings. We find that the initial investment cost is the biggest deterrent of supporting such measures. The implied rate of return that tenants demand for their potential investment in retrofits is excessively large when assuming a time horizon of two or more years.

Some limitations of the research conducted in this paper should be noted. Firstly, making choices that have no tangible consequences for the participants in an experiment may lead to hypothetical bias (Hensher, 2010) as well as social desirability bias (Fisher, 1993). Furthermore, the sample size is relatively small, which limits the ability to estimate more complex interaction effects. Still, we find results of statistical significance that have economic meaning.

Naturally, the decision to undertake a home retrofit is more complex than can be simulated in an online experiment such as the one designed and conducted in this study. Additionally, retrofitting is not necessarily a binary choice; actual retrofitting outcomes may vary greatly based on the characteristics of the individual home and the preferences and motives of both landlords and tenants. In addition, the regulatory framework may have a strong influence on the specific outcomes and may limit the options of both parties regarding efficiency investments.

This research has several main implications, namely:

1. the most severe obstacle to renters' willingness to invest in their non-owned dwellings is the initial investment cost;
2. renters' desired return on investment is either prohibitively large, or the time horizon considered is short, i.e. less than 2 years;
3. renters show a significant willingness to pay to achieve CO_2 emission reductions through retrofits.

Based on these research findings, some promising ways to promote stronger inclusion of renters in retrofitting would therefore be to:

1. lower investment costs for low-income households, e.g. through investment subsidies;
2. promote long-term or permanent rental contracts so that renters have a longer time horizon for their investments;
3. advertise the potential for CO_2 emission savings through retrofitting.

Future research avenues may include large-scale field experiments where actual retrofits are conducted, which would allow researchers to observe renters' choices and behaviors in the field. Furthermore, understanding the different motivations and incentives of both landlords and tenants may be a fruitful area for further investigation. If these motivations are understood more thoroughly, policy makers can create specific financing instruments that solve these issues and therefore promote higher rates of retrofitting.

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